ABSTRACT
Great Lakes Photonics Symposium
June 7-11 2004
Conference: Aerospace Applications

1. **PAPER TITLE** ***Examples of Current and Future Uses of Neural-Net Image Processing for Aerospace Applications***

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3. **PRESENTATION PREFERENCE Oral Presentation**

4. **PRINCIPAL AUTHOR'S BIOGRAPHY Dr. Arthur J. Decker has worked in Optical Metrology at NASA's Glenn Research Center for about 38 years. He has specialized for several years in neural-net processing of interference fringe patterns for non-destructive testing and fault recognition. Currently he is applying optical and neural-net techniques to the quantum technologies including nanotechnology and optical computing.**

5. **ABSTRACT TEXT**

Feed forward artificial neural networks are very convenient for performing correlated interpolation of pairs of complex noisy data sets as well as detecting small changes in image data. Image-to-image, image-to-variable and image-to-index applications have been tested at Glenn. Early demonstration applications are summarized including image-directed alignment of optics, tomography, flow-visualization control of wind-tunnel operations and structural-model-trained neural networks. A practical application is reviewed that employs neural-net detection of structural damage from interference fringe patterns. Both sensor-based and optics-only calibration procedures are available for this technique. These accomplishments have generated the knowledge necessary to suggest some other applications for NASA and Government programs. A tomography application is discussed to support Glenn's Icing Research tomography effort. The self-regularizing capability of a neural net is shown to predict the expected performance of the tomography geometry and to augment fast data processing. Other potential applications involve the quantum technologies. It may be possible to use a neural net as an image-to-image controller of an optical tweezers being used for diagnostics of isolated nano structures. The image-to-image transformation properties also offer the potential for simulating quantum computing. Computer resources are detailed for implementing the black box calibration features of the neural nets.

6. KEYWORDS Neural Nets, Calibration, Image Processing, Nanotechnology

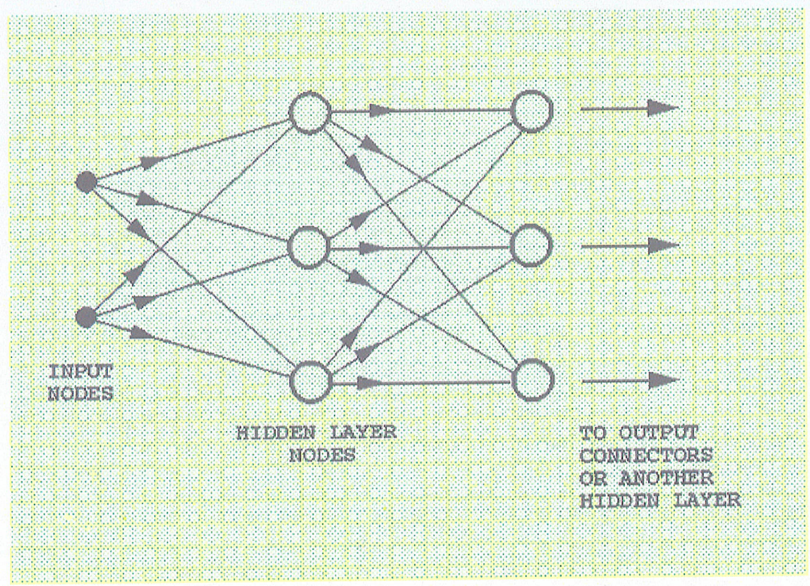
Examples of Current and Future Uses of Neural-Net Image Processing for Aerospace Applications

Arthur J. Decker

Optical Instrumentation Technology Branch

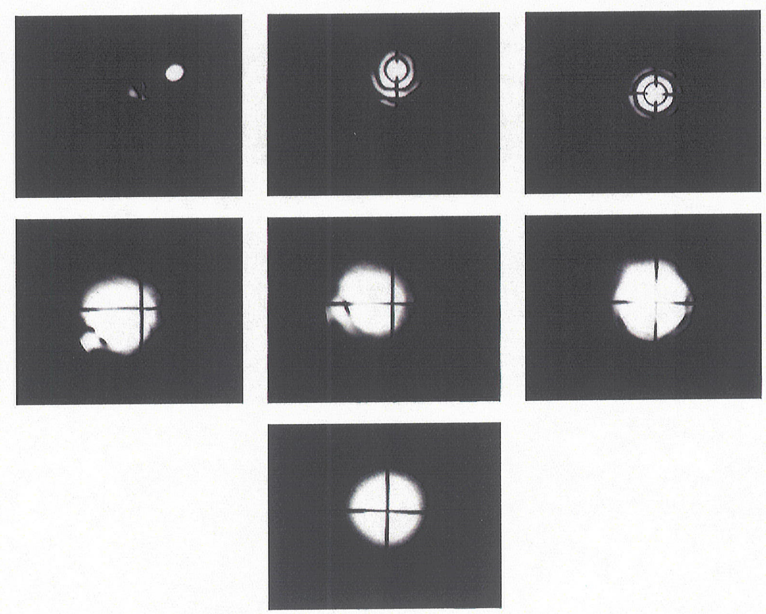
General Objective

- Given
  - Inputs of 10's, 100's, 1000's Up To 10,000 Channels of Optical Data.
  - Outputs of a Few to 10,000 Responses.
- Train
  - Neural Net To
    Map Generally Inputs To Outputs.



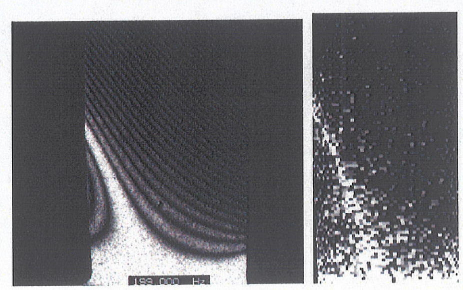
Format I—A Few Image Characteristics

- Inputs
  - Intensity CM Position
  - Pattern Characterization
  - Last Alignment Control Operated
- Outputs
  - Alignment Control To Be Operated
  - New CM Position
  - New Pattern Characterization



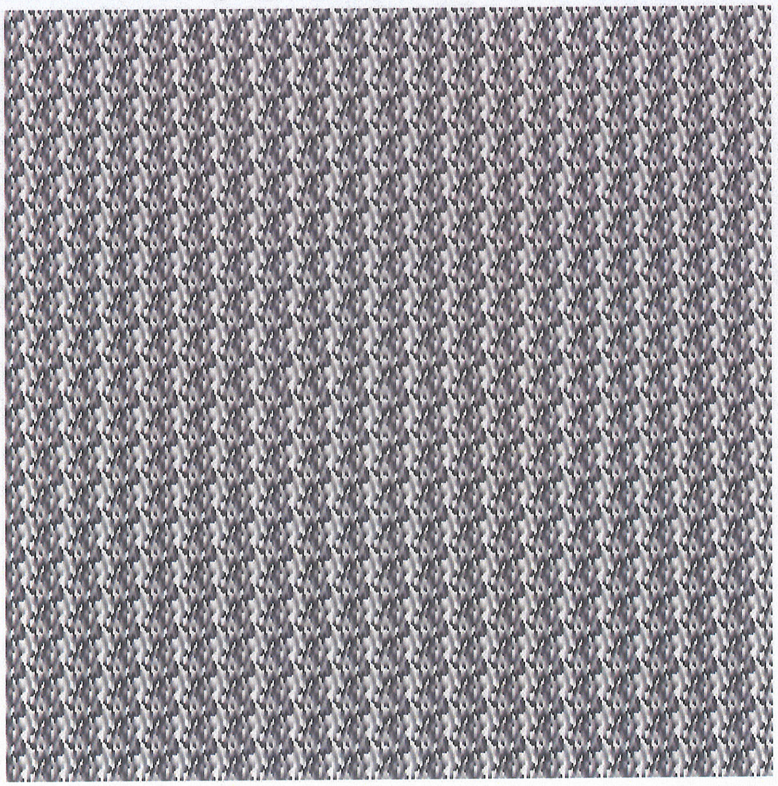
Format II—Sub-Sampled Images

- Deterministically
  - Flow Visualization.
  - Map Images To Wind Tunnel Sensor Outputs.
- Randomly
  - Speckled Fringe Patterns.
  - Use Trained Net as a Null Detector for Damage.

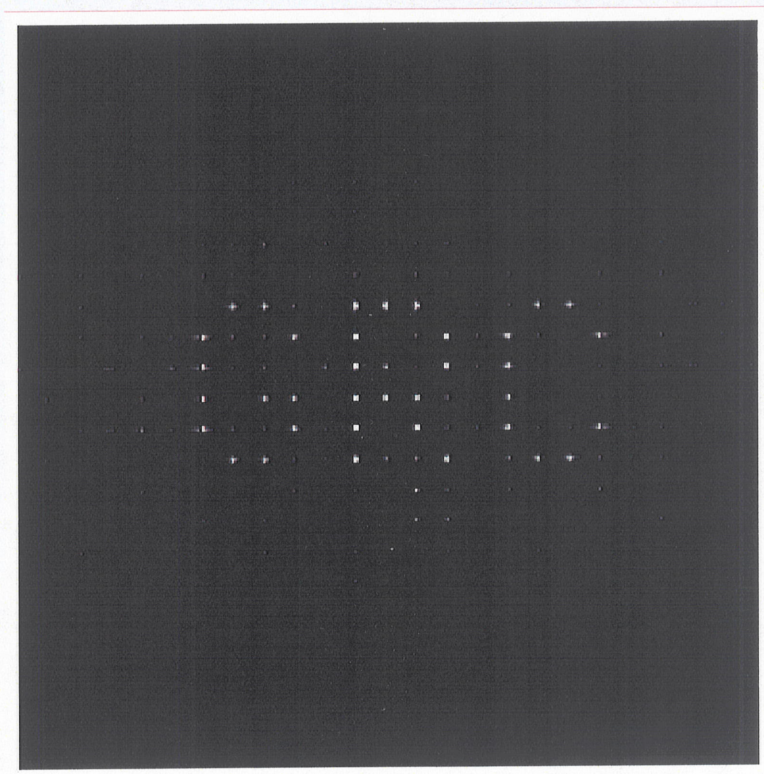


Format III—Scaled and Tiled Images

- Optical Tweezers Control
  - To Manipulate and Calibrate Nanotube Sensors.
  - Multiple Nets and Multiple Scales.
  - Nets Control a SLM.

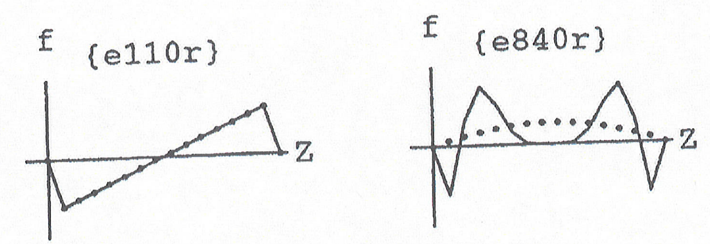


SLM-Generated Trap Pattern

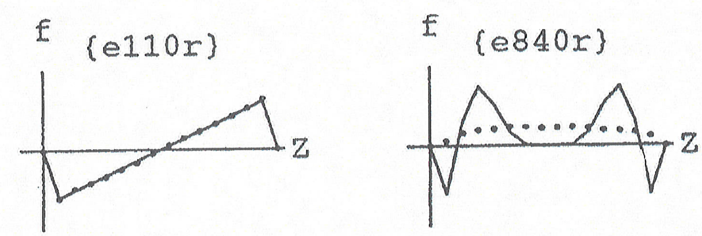


Format IV—Full Optical Data

- Tomography
  - Icing Tunnel Tomography Provides Only 300-400 Projections Through Fibers.
  - Neural Net Tomography Appears to Self Regularize.



Computed Tomography



Neural-Net Tomography

Randomly Sub-Sampled Images

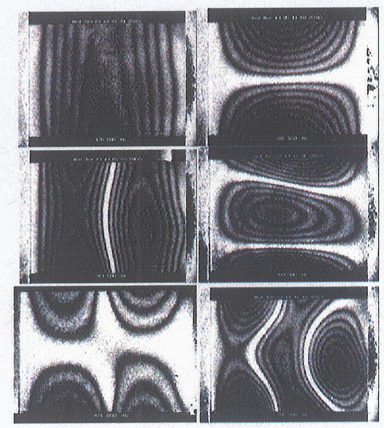
- Easy to Determine
  - Neural-Net Architecture.
  - Training Set Composition.
  - Required Computer Resources.
- NDE Application
  - Handled Like a Calibration.
  - Subject to Simulation.

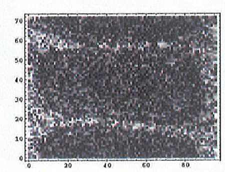
Speckled Fringe Patterns of Vibrating Structures

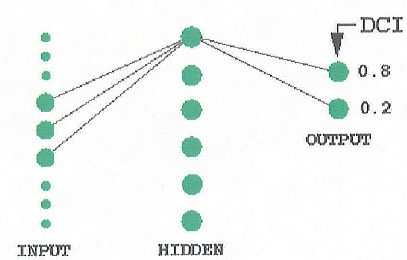
- Noise: Speckle Effect, Vibration Amplitude, Air, Synchronization and Optical System Fluctuations.
- Rule 1: Train the Net with Noise Samples Equal to 10% of the Number of Pixel Sub-Samples for Noise Immunity.
- Rule 2: Use About 3 Hidden-Layer Nodes Per Training Class.

NDE Application

- Process
  - Excite Low Amplitude Vibrations.
  - Sub-Sample Randomly.
  - Divide Records Into Two Classes To Train.
  - Assign Different Output Indices to Classes.
  - Outputs Become Sensitive to Damage Induced Mode Shape Changes.

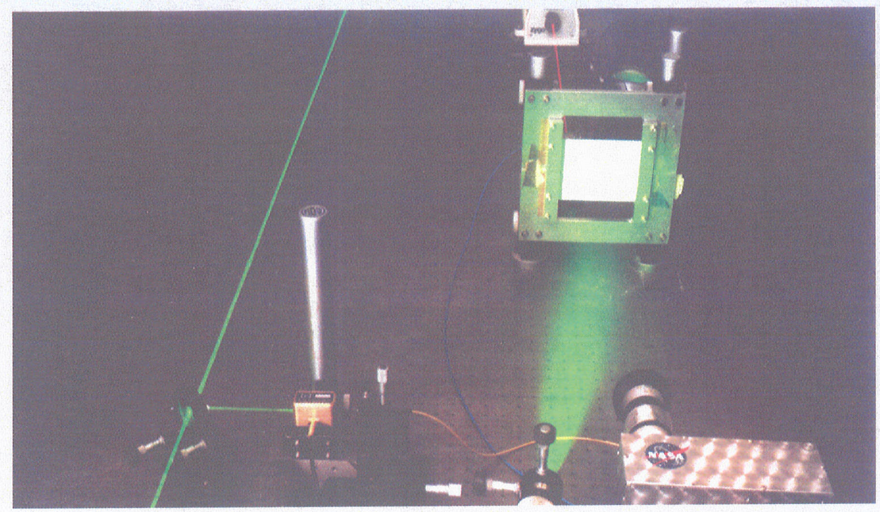


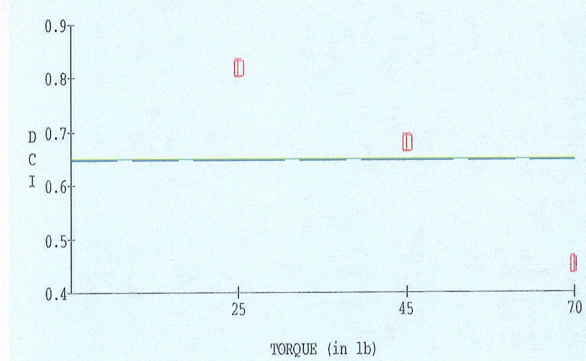




Mode-Shape Variations

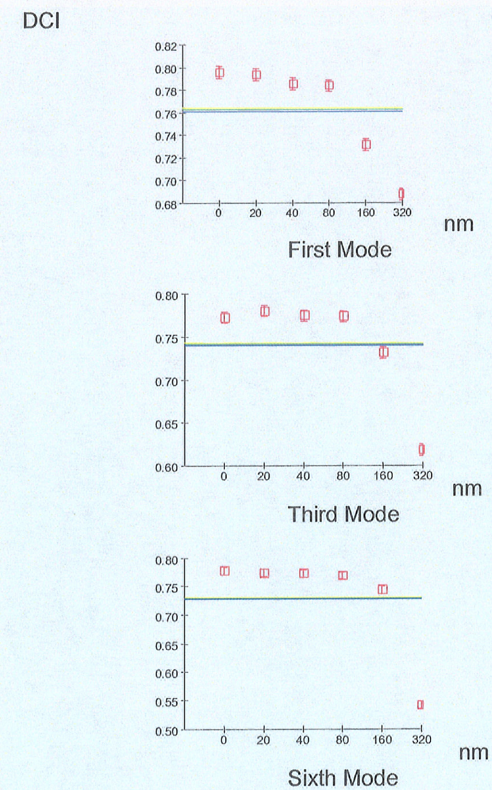
- Change Boundary Conditions.
- Example
  - 1728 Pixels
  - Class 1: One Mode
  - Class 2: Three Modes
  - 173 Patterns Per Mode.
  - Hidden Nodes: Six.





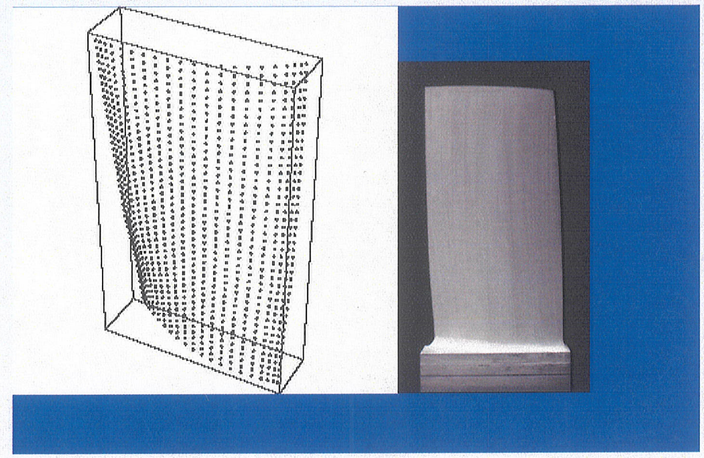
Optics-Only Calibration

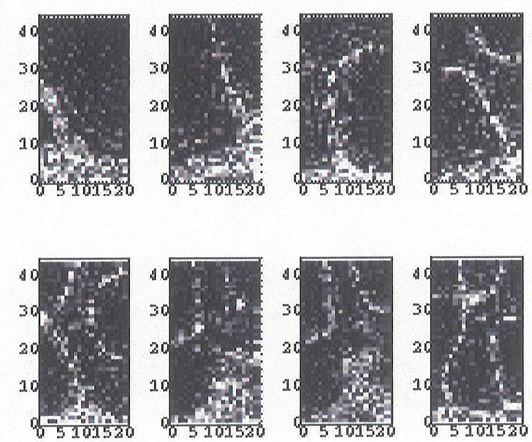
- Second Class
  - Add Small Amounts Of Other Modes to Mode to Be Monitored.
  - Need Many (2nd, 5th, 7th, 8th, 9th, 10th) For Position Independent Sensitivity.
- Measure Response
  - Use Modes That Differ From Training Set (1st, 3d, 6th).
- Lab Sensitivity ~100 nm Peak-to-Peak, 50 nm Amplitude.



Increasing the Sensitivity

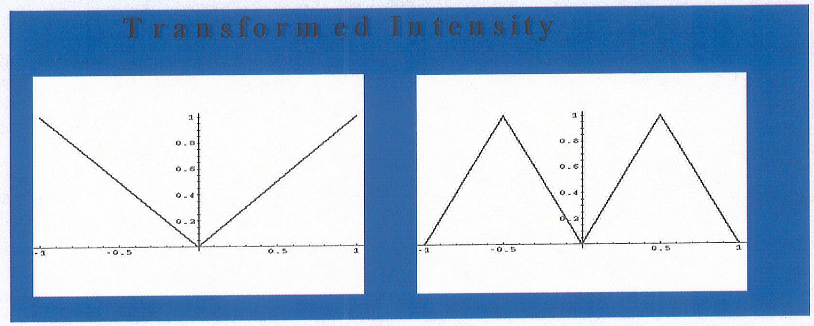
- Form Second Class From Smaller Vibration Amplitudes (80 nm Peak-To-Peak).
- Use Model Data
  - Contaminate 4th Mode.
  - Use 2nd and 3d To Train.
  - Test With 6th.
- Need To Transform Inputs For Training.

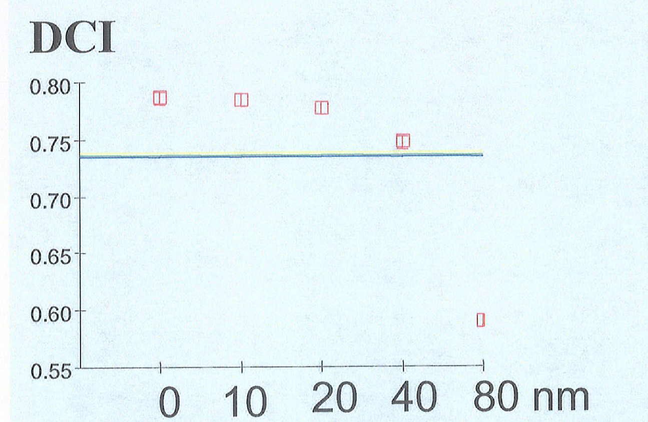




Folding Transformation

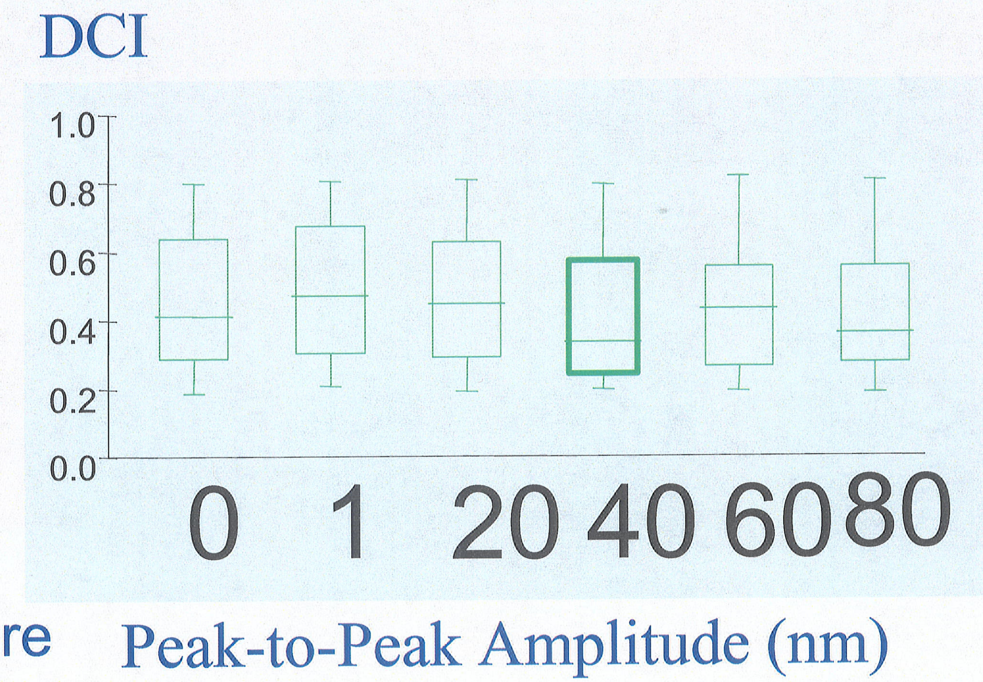
- Increases Sensitivity Until First Systematic Effect is Learned.
- Transforms the Input Intensity.
- Model Example
  - Needs 9 Folds.
  - Needs 9 Hidden Nodes.
  - Generates 10 nm Amplitude Sensitivity.





Folded Laboratory Data

- Training
  - Appears To Succeed With Only 5 Folds.
- Folding In Fact
  - Creates Net That Merely Responds To Environmental Effects.
- Amplitude Sensitivity Is Truly 50 nm.
- 0 and 1 Represent Before And After No-Excitation Condition.



Future Work and Potential Future Work

- Development of Neural-Net Controller for Optical Tweezers (Scaling and Tiling Approach).
- Add Neural-Net Processor to Icing Tunnel Tomography System.
- Develop Neural-Net Quantum Computer Simulator.

Concluding Remarks

- Discussed Four Approaches to Matching the Processing Capability of Software Neural Nets to Image Data.
- Discussed the Random Sub-Sampling Approach and the Speckled Fringe Pattern Application.
- Discussed Optics Only Calibration of a Neural Net Null Detector for Damage Detection.